9 Food and Agricultural Industries

Disclaimer: Emission factors in AP-42 are neither EPA-recommended emission limits (e.g., best available control technology or BACT, or lowest achievable emission rate or LAER) nor standards (e.g., National Emission Standard for Hazardous Air Pollutants or NESHAP, or New Source Performance Standards or NSPS). Use of these factors as source-specific permit limits and/or as emission regulation compliance determinations is NOT recommended by EPA. Because emission factors essentially represent an average of a range of emission rates, approximately half of the subject sources are expected to have emission rates greater than the emission factor, and the other half are expected to have emission rates less than the emission factor. As such, EPA does not recommend using emission factors as limits or standards. This could cause, for example, a permit limit using an AP-42 emission factor resulting in approximately half of the sources being in noncompliance. We recommend source testing be done for the best possible emission values. For more information on the use of emission factors, please refer to the AP-42 Introduction.

9.4 Livestock & Poultry Feed Operations

9.4.1 General Background[1]

The EPA defines an animal feeding operation (AFO) as a lot or facility where: (1) livestock or poultry have been, are, or will be confined and fed for a total of 45 days or more in any 12-month period, and (2) crops, vegetative forage cover, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility (40 Code of Federal Regulations, Section 122.23). The stipulation of the absence of vegetative cover intentionally excludes operations where animals are maintained on pasture or rangeland.

An AFO includes animal confinement structures, a system for managing manure, and a land application site for disposing of manure. Animal confinement structures may be totally enclosed with full-time mechanical ventilation, partially enclosed structures with or without mechanical ventilation, or paved or unpaved open lots. The manure management system collects manure, which includes a combination of fecal matter, urine, and other materials (e.g., bedding, waste feeds, wash water), and stores the manure until land application. Depending on the type of animal raised and the confinement method, manure can be solid, liquid, or slurry. Where the AFO handles manure as a solid, storage may occur within the confinement facility (e.g., the manure accumulates on or beneath the flooring) or in covered or uncovered stockpiles. For liquid or slurry manure management systems, manure may be stored in an integral tank, such as a storage tank under the floor of a confinement building, or flushed to an external facility, such as a pond or basin. Operators may also transfer liquid or slurry manures to an anaerobic lagoon, where the manure undergoes stabilization through biological treatment to reduce volatile solids and odor emitted from manure prior to land application. Table 9.4-1 presents an overview of the most common methods of confinement and manure management for large AFOs; however, the configuration and operation of individual AFOs varies depending on the animal type, regional climatic conditions, business practices, and preferences of the operator.

Table 9.4-1. COMMON TYPES OF CONFINEMENT AND MANURE MANAGEMENT SYSTEMS

Animal Type	Confinement Method	Manure Management System
Broilers and Turkeys	Enclosed building	Manure integrated with confinement[a] or stored in open or covered stockpiles
Layers	Enclosed building	Manure integrated with confinement[a]
Layers	Enclosed building	Manure flush from housing to ponds and anaerobic lagoons
Swine	Enclosed building	Manure integrated with confinement[a] or tanks, ponds, anaerobic lagoons
Dairy	Enclosed building and open lots	Manure removed from housing to anaerobic lagoons, tanks and ponds, and uncovered manure stockpiles
Beef	Open lots	Manure stored in uncovered stockpiles

[a] The confinement building stores manure until land application.

Land application sites (e.g., cropland, pastures) serve as the ultimate disposal method for AFO manure. Solid manure can either be applied to the soil surface with or without subsequent incorporation (e.g., disc harrowing). Liquid and slurry manure can be applied to the surface of soil, applied to the soil surface followed by incorporation, or injected into the soil.

Animal feeding operations can emit ammonia (NH_3), hydrogen sulfide (H_2S), volatile organic compounds (VOCs), and particulate matter (PM). These emissions have a variety of environmental and human health effects. The compounds primarily responsible for the odors associated with AFOs are VOCs, H_2S, and other reduced sulfur compounds. Volatile organic compounds also contribute to the formation of atmospheric ozone, which is a respiratory irritant. Some VOCs are designated in the Clean Air Act (CAA) as hazardous air pollutants (HAPs). Ammonia also is a source of odor from AFOs, but to a lesser degree because NH_3 rapidly disperses in the air. Ammonia readily adheres to particles in the air due to its cohesive properties. Once released to the atmosphere, NH_3 is deposited back to the earth in one of two forms. Ammonia also can be converted to ammonium sulfate or ammonium nitrate that can contribute to fine particulate concentrations ($PM_{2.5}$). When deposited back to the earth, these aerosols contribute to nutrient over-enrichment in aquatic systems and acidification of the environment.

The Source Classification Codes (SCC) for this sector are:

- 30202001 – Industrial Processes – Food and Agriculture – Cattle Management – Beef Cattle Feedlots: Feedlots: General
- 30202010 – Industrial Processes – Food and Agriculture – Cattle Management – Range Cattle: Enteric, Confinement, Manure Handling, Storage, Land Application
- 30202020 – Industrial Processes – Food and Agriculture – Cattle Management – Dairy Cattle: Enteric, Confinement, Manure Handling, Storage, Land Application
- 30202050 – Industrial Processes – Food and Agriculture – Cattle Management – Feedlot Cattle: Enteric, Confinement, Manure Handling, Storage, Land Application

- 30202070 – Industrial Processes – Food and Agriculture – Cattle Management – Silage pile - AFO: Storage and Handling
- 30202080 – Industrial Processes – Food and Agriculture – Cattle Management – Silage TMR - AFO: Storage and Handling
- 30202101 - Industrial Processes – Food and Agriculture – Non-Cattle Livestock Management – Eggs and Poultry Production: Manure Handling: Dry
- 30202105 - Industrial Processes – Food and Agriculture – Non-Cattle Livestock Management – Eggs and Poultry Production: Manure Handling: Wet
- 30202120 - Industrial Processes – Food and Agriculture – Non-Cattle Livestock Management – Broilers: Enteric, Confinement, Manure Handling, Storage, Land Application
- 30202130 - Industrial Processes – Food and Agriculture – Non-Cattle Livestock Management – Layers: Enteric, Confinement, Manure Handling, Storage, Land Application
- 30202140 - Industrial Processes – Food and Agriculture – Non-Cattle Livestock Management – Turkeys: Enteric, Confinement, Manure Handling, Storage, Land Application
- 30202150 - Industrial Processes – Food and Agriculture – Non-Cattle Livestock Management – Swine: Enteric, Confinement, Manure Handling, Storage, Land Application
- 30202160 - Industrial Processes – Food and Agriculture – Non-Cattle Livestock Management – Sheep: Enteric, Confinement, Manure Handling, Storage, Land Application
- 30202170 - Industrial Processes – Food and Agriculture – Non-Cattle Livestock Management – Horses: Enteric, Confinement, Manure Handling, Storage, Land Application
- 30202180 - Industrial Processes – Food and Agriculture – Non-Cattle Livestock Management – Other Livestock: Enteric, Confinement, Manure Handling, Storage, Land Application
- 30290001 - Industrial Processes – Food and Agriculture – Fuel Fired Equipment – Distillate Oil (No. 2): Process Heaters
- 30290002 - Industrial Processes – Food and Agriculture – Fuel Fired Equipment – Residual Oil: Process Heaters
- 30290003 - Industrial Processes – Food and Agriculture – Fuel Fired Equipment – Natural Gas: Process Heaters
- 30290005 - Industrial Processes – Food and Agriculture – Fuel Fired Equipment – Liquified Petroleum Gas (LPG): Process Heaters
- 30299998 - Industrial Processes – Food and Agriculture – Other Not Specified – Other Not Classified

9.4.2 Livestock Husbandry Description

9.4.2.1 Broiler Operations[1]

Broiler production is the raising of chickens of either sex for meat. A broiler is a young chicken characterized as having tender meat, flexible breastbone cartilage and soft, pliable smooth-textured skin. Broiler production is a highly vertically-integrated industry, wherein a common owner or parent company is involved in several phases of the supply chain. For example, a parent company, or integrator, typically operates or contracts every aspect of the broiler production process (e.g., hatcheries, production houses, slaughterhouses, meat packing plants, feed production facilities, and food distributors).

For broiler production operations, the integrator typically provides the birds, feed, medicines, transportation, and technical support, under contract, to growers who provide the labor and the production facilities to raise the birds from hatchlings to market weight. The contract grower receives a minimum guaranteed price for the birds moved for market. More than 90 percent of all chickens raised for human consumption in the United States are produced by growers working under contract with integrators.[2] Because of this vertical integration, management strategies at the facility level tend to be more uniform than in other sectors of AFOs.

The length of the grow-out period ranges from 28 to 63 days, depending on the size of the bird desired. The grow-out period includes a brooding phase that begins when day-old chicks are placed in a heated section of a broiler house known as the brood chamber. The brood chamber is initially maintained at an elevated temperature (e.g., 85 to 95 °F), which is gradually decreased during the first few weeks of the birds' growth. As the growing birds need floor space, the remainder of the house is opened, and the chicks are grown to market weight.

Broilers are produced to meet specific requirements of customers, which can be retail grocery stores, fast-food chains or institutional buyers. For broilers, the typical grow-out period is 49 days, resulting in an average bird weight of 4.5 to 5.5 pounds. The grow-out period may be as short as about 28 days to produce birds weighing 2.25 to 2.5 pounds, commonly referred to as a Cornish game hen. For producing roasters weighing 6 to 8 pounds, the grow-out period is up to 63 days.

Broiler houses are operated on an "all in-all out" basis (i.e., all birds are removed at the end of the grow-out period) and require time for cleaning (e.g., decaking) and repair between flocks. For broilers, five to six flocks per house per year is typical; however, the number of flocks raised per year is lower for roasters and higher for Cornish game hens. Female broilers grown to lay eggs for replacement stock are called broiler breeders and are usually raised on separate farms. These farms produce only eggs for broiler replacements. A typical laying cycle for hens is about 1 year, after which the hens are sold for slaughter.

9.4.2.2 Turkey Operations[2]

Turkey production is very similar to broiler production with the principal difference being the size of bird produced and the length of the grow-out cycle. Due to the longer grow-

out cycle for turkeys, there typically are only two or possibly three grow-out cycles per year versus five to six for broilers.

The growth of a turkey is commonly divided into two phases: brooding and grow-out. The brooding phase of a poult (young turkey) is from 1 day old to about 6 to 8 weeks. During this time, the poults need supplemental heaters to keep the ambient temperature at 90 to 95 °F. Thereafter, the producer decreases the temperature by 5 °F for the next 3 weeks until the temperature reaches 75 °F. Brooding can occur either in a partitioned area of the house called the brooding chamber or in an entirely separate house. Separate poult housing is more prevalent in larger operations for disease control. The grow-out phase starts after the brooding phase. Depending on the sex of the birds, the grow-out phase typically lasts up to 21 weeks, resulting in a live slaughter weight of between 30 and 37 pounds. At the end of the production cycle, the house is completely cleaned out. Typically, two flocks of turkeys are produced annually because of the longer grow-out cycle and the somewhat seasonal demand for turkey. As the demand for turkey has increased and become somewhat less seasonal, a third flock may be started with grow-out completed in the following year. Turkeys are fed primarily corn-soybean based diets, which also may include various cereal grains and a variety of other ingredients.

Essentially all turkey production occurs in partially or totally enclosed facilities divided into two or three chambers. Newly hatched turkeys are placed in a brood chamber. As with broiler chickens, the second, or second and third chambers, are opened to provide more floorspace per bird as the birds grow. In cold weather, some heat may be provided throughout the grow-out cycle.

Some turkey producers use separate brood and growing houses and move birds from the brooding house to the growing house after about six to eight weeks. Another production practice is to use the brood chamber in a house exclusively for brooding and use the remainder of the house for grow-out after the birds reach the age of six to eight weeks. These management systems are known as two-age management systems. Confinement facilities for turkeys are similar to those used for broilers typically being40 feet wide but usually only 300 to 400 feet in length. They also may be totally enclosed or partially enclosed with partially open, screened sidewalls that can be closed using curtains. Size of sidewall opening depends on climate and may be as much as 4 to 5 feet high in warm climates. Partially enclosed facilities are more common in warmer climates such as the South and Southeast whereas totally enclosed facilities are more common in the north. As with broilers and laying hens, totally enclosed facilities generally have automatic delivery and mechanical ventilation. Negative pressure ventilation is the principal method of ventilation used.

Turkeys are raised on litter, typically sawdust or wood shavings. Total clean-out of brood chambers and brood houses after each flock is common. In growing chambers or houses, cake is removed between flocks and a total clean-out occurs annually. Other aspects of turkey manure handling are similar to broiler operations. After removal from the housing facilities, manure can be directly applied to the land (if available), stored in covered or uncovered stockpiles prior to land application, or pelletized and bagged for use as commercial fertilizer. In the turkey sector, the use of litter sheds to store cake and little from total clean-outs is

emerging. However, storage of these materials in uncovered piles continues to be a common practice.

9.4.2.3 Layer Operations[1]

Layers (defined as sexually mature female chickens capable of producing eggs[3]) typically enter the layer AFO at an age of approximately 18 weeks and stay in a layer house for approximately 18 months.[4] Layer operations in the United States range in size from small farm of less than 20,000 birds to farm that are well over 100,000 birds. The largest facilities typically represent less than one percent of the total number of operations but confined over 55 percent of the laying hens.[2] Geographically, the most operations occur in the Midwest; however large production facilities are evenly spaced throughout the country.

The emptying of a flock from a house and the placement of a new flock can take 1 to 2 months. Commonly, the management practice of induced molting, which involves feed withdrawal, change of feed diet, and sometimes light exposure,[5] is used in layer operations to optimize egg production and quality.[5, 6] Furthermore, induced molting allows flocks to lay for additional time periods, thus reducing cost.[6] Molting typically lasts around 4 to 6 weeks[5] and consists of three phases: a pre-molt phase, the weight loss phase (molt period), and a return to production phase.[5,7]

Most U.S. layer operations confine hens in cages to allow for automation of egg removal and the confinement house is mechanically ventilated to remove moisture and carbon dioxide. In single-story houses, manure falls through the cage bottoms and accumulates in a shallow pit that is periodically flushed or scraped to remove the manure to external storage (e.g., manure shed) or to land application. In two-story confinement houses, referred to as high-rise (HR) houses, the upper level of the house holds the hen cages and the ground floor provides for manure accumulation and storage. Operators typically remove the accumulated manure from HR houses manually (e.g., using a skid loader) in between flocks on an annual or more frequent schedule.[3] At layer operations where the hen cages are stacked vertically in multiple levels, a system of conveyor belts catches the manure that falls from the cages and removes the manure from the confinement house on a quasi-continuous schedule to external storage or to land application.

Layer confinement buildings are typically mechanically ventilated. In HR houses, ventilation air is designed to drawn down through the confinement level to the ground level, where the air movement serves to dry the accumulated manure before the ventilation air exits house.[8, 9]

9.4.2.4 Swine Operations[1]

Swine operations breed and grow pigs for meat. Typical swine operations combine various stages of swine development. The number of swine sites in the United States has been steadily declining since 1959; however, the number of pigs marketed has increased. This is in part due to improvements in animal health (i.e., decrease in mortality rates) and increased sow fertility. It is also characteristic of the domestic swine industry becoming increasingly

dominated by large totally-enclosed confinement operations capable of handling 5,000 animals or more at a time.

The production cycle for swine has three phases: farrowing, nursing, and finishing. Some farms specialize in a single phase of the growth cycle, while other farms may handle two or all three phases. The first phase begins with breeding and gestation over a 114-day period followed by farrowing (giving birth). After farrowing, the newly born piglets normally are nursed for a period of three to four weeks until they reach a weight of 10 to 15 pounds. Sows can be bred again within a week after a litter is weaned. Sows normally produce five to six litters before they are sold for slaughter. After weaning, pigs are relocated to a nursery where they are typically fed a corn/soybean meal-based diet that may include small grains such as wheat and barley and other ingredients until slaughtered. Nursery operations receive weaned pigs and grow them to a weight of 40 to 60 pounds. The third phase of swine production is the grow-finish phase where the gilts (young females) and young castrated boars (males) not retained for breeding are fed until they reach a market weight, typically between 240 and 280 pounds. Grow-finish phase usually takes between 15 and 18 weeks, and animals normally are slaughtered at about 26 weeks of age.

As of the 2022 USDA Census of Agriculture, the most common type of swine operation is the grow-finish operation, followed by the farrow-to-finish operation which encompasses all three phase of swine production. Another common production mode is the combination of the farrowing and nursing phases, which provide feeder pigs for grow-finish operations. Although not as common, some newer farms may operate only the farrowing phase or only the nursery phase. These operations may be linked by common ownership or separately owned, but all under contract with a single integrator. Thus, pigs may begin their life-cycle in a sow herd on one site, move to a nursery on another, and then move again to a finishing facility.[10] Specialized operations can take advantage of skilled labor, expertise, advanced technology, streamlined management, and disease control.

Typically, each phase of the swine production cycle occurs in separate, specially-designed facilities. Gestation barns house pregnant sows before birthing. Typical gestation barns confined sows in individual pens to reduce animal stress and minimize fighting. Because farrowing operations require intense management to reduce piglet mortality, barns used for this cycle contain farrowing pens for individual sows and protected areas for piglets. Nursery buildings are typically designed to provide a clean, warm, dry, and draft-free environment to minimize animal and injury, and to promote rapid growth. Nursery buildings are cleaned and disinfected thoroughly between groups of pigs to prevent transmission of disease from one herd to another. Finishing pigs require less intensive management and can tolerate greater variations in environmental conditions without incurring health problems. Consequently, the number of pigs confined in finishing barns (e.g., one pig for every six square feet of floor space) is much higher than in barns used for farrowing and nursing operations.

Four principal types of waste management systems are used with total and partially enclosed confinement housing in the swine industry: deep pit, pull-plug pit, pit recharge, and flush systems. Other practices are used, but these are the predominant practices that swine operations currently use. The deep pit, pull-plug pit, and pit recharge systems are used with

slatted floors, whereas flush systems can be used with either solid or slatted floors. For flush systems, either fresh water or supernatant from an anaerobic lagoon transports accumulated wastes to an anaerobic lagoon. The pit may be flushed daily or as often as every two hours; the frequency depends on design characteristics such as channel length and slope and volume of water used per flush. In pit recharge systems, relatively shallow pits are drained periodically by gravity to an anaerobic lagoon. The frequency of draining varies but four to seven days is standard. Following draining, the empty pit is partially refilled with water, which can be supernatant from the anaerobic lagoon. Pull-plug pits are similar to pit recharge in that pit contents are drained by gravity to a storage or stabilization system. Pits are drained frequently, often each week or every two weeks. However, water is not added back into the pit. The system relies on the natural moisture in the manure. Deep pits are similar to pull-plug pits in that they store the manure directly under a slatted flooring system, and no water is added into the pit. They differ in that deep pits are typically sized to collect and store six months of waste. The accumulated manure has a higher solids content than pull-plug systems and emptied by pumping. To reduce odor, NH_3, and H_2S concentrations in confinement facilities with deep pits, ventilation air may flow through the animal confinement area, down through the slatted floor, and over the accumulated manure before discharge from the building. Alternatively, deep pits may be ventilated separately.

Most large swine farms have from 6 to 12 months of manure storage capacity before removal to land application.[11] Storage takes place in either an anaerobic lagoon or a storage facility. Anaerobic lagoons provide both storage and stabilization of manure through biological activity. Typical storage facilities include deep pits, tanks, and earthen ponds or basins (these storage facilities do not typically provide for manure stabilization). The use of storage tanks and ponds generally is limited to operations with deep pits and pull-plug pits where manure is handled as a slurry. Pit recharge and flush systems typically use anaerobic lagoons, because of the need for supernatant for use as recharge or flush water.

9.4.2.5 Beef Cattle Operations

Beef cattle operations breed and grow beef for meat. There are three different types of operations in the beef industry: cow-calf, backgrounding, and finishing. These operations are typically conducted at separate locations that specialize in each phase of production. Cow-calf operations are a source of the heifers and steers (castrated males) fed for slaughter. Backgrounding or stocker operations prepare weaned calves for finishing on high energy rations to promote rapid weight gain. The final phase of the beef cattle production cycle is called the finishing or feedlot phase, during which the cattle grow from approximately 400 pounds to slaughter weight (e.g., 1,000 to 1,250 pounds) over a duration of 150 and 180 days.

The types of animal confinement vary by production phase. Cow-calf and backgrounding phases of the beef production cycle are primarily pasture or rangeland based. Backgrounding operations may be pasture or dry-lot based or a combination. In the finishing phase, heifers and steers are typically fed to slaughter weight in open confinement facilities known as feedlots or feed yards, which may be partially paved. Generally, paving, if present, is limited to a concrete apron typically located along feed bunks and around waterers, because these are areas of heaviest animal traffic and manure accumulation.[12]

Beef cattle manure produced in confinement facilities generally is handled as a solid. At open lots, solid manure is typically collected for removal or stockpiling by scraping using tractor-mounted blades, pan scrapers, and front-end loaders. Run-off from open feedlots can be either liquid or slurry and is conveyed to storage ponds that may be preceded by settling basins to reduce solids entering the ponds. At totally enclosed confinement facilities, manure can be removed by scraping or by flushing accumulated manure to an earthen anaerobic lagoon for stabilization and storage using a large volume of water. Manure collected from confinement facilities may be stored, stabilized to reduce odor and volatile solids (e.g., stacking, composting), directly applied to land onsite, or transported off-site for disposal.[2]

9.4.2.6 Dairy Operations

Dairy operations are defined as those operations producing milk, raising dairy replacement heifers, or raising calves for veal. Typically, dairy operations combine milk production and the raising of heifers (immature females) as replacements for mature cows that no longer produce milk economically. However, some milk producers obtain some or all replacement heifers from operations specializing in raising heifers (stand-alone heifer operations). Although some dairies raise veal calves, veal production is typically specialized at operations solely raising veal calves.

The primary function of a dairy is the production of milk, which requires a herd of mature dairy cows that are lactating. To produce milk, the cows must be bred and give birth. Therefore, a dairy operation will have several types of animal groups present, including calves, heifers, mature cows (lactating and dry cows), veal calves, and bulls.

When not being milked, the lactating and dry herd are typically confined in freestall barns, drylots, tie stalls/stanchions, pastures, or combinations of these. Dry cows are confined in loose housing or freestalls.[13] Confinement barns are mechanically ventilated where a system of fans draw air into the barn, or naturally ventilated where operators raise or lower side curtains to allow ambient air to flow through the barn.[14]

Mature cows that are close to calving are typically confined to sod pastures in warmer climates or during the summer. Alternatively, the cows may be housed in multiple-animal or individual pens prior to calving. Drylots are used to house calves, and heifers. Lactating cows require milking at least twice per day and are either milked in their tie stalls or are led into a separate milking center. Milking centers (also called parlors) are separate buildings, apart from the lactating cow confinement. A holding area confines cows that are ready for milking. Usually, the holding area is enclosed and is a part of the milking center, which in turn, may be connected to the barn or located in the immediate vicinity of the cow housing.

The methods used to collect manure from confinement and milking centers depend largely on the consistency of the manure. Solid manure on drylots is typically removed by scraping using a tractor-mounted blade. Manure accumulations in freestall barns are typically collected and removed by mechanized scraping systems or by using a flush system. For milking centers, flushing systems are used exclusively to remove manure. Manure collected from the confinement facilities and milking centers may be transferred directly to storage or undergo solids separation or stabilization prior to storage and land application.

9.4.3 AFO Emissions[1]

9.4.3.1 Gases

Gaseous emissions from AFOs result from the microbial decomposition of manure. Microbial decomposition of manure and the formation of gaseous compounds begin immediately upon excretion and continue until the manure is incorporated into the soil at the land application site. The composition of gas emissions and the subsequent emissions rates from AFOs depends on several factors: (1) the presence of an aerobic or anaerobic microbial environment, (2) the chemical precursors present in the manure, and (3) pH of the manure.

Gaseous emissions from AFOs are also affected by manure temperature and length of time before incorporation into soil. Temperature affects gas phase vapor pressure, and therefore, the volatility and emissions of water-soluble substances (NH_3), are greater at higher temperatures. Higher temperatures also favor the microbial processes that generate gaseous substances. Long periods of manure residence time in confinement, storage, or stabilization facilities before incorporation into soil provide greater opportunities for anaerobic breakdown of manure and volatilization of gaseous emissions to the air. The method of applying manure can also affect emissions (e.g., emissions from land-applied manure not immediately incorporated will be higher than with rapid incorporation by disking or plowing).

9.4.3.1.1 Ammonia

Ammonia is a by-product of the microbial decomposition under both aerobic and anaerobic conditions of organic nitrogen compounds present in manure. The nitrogen compounds originate from unabsorbed nutrients in manure and in urine (urea from mammals and uric acid from poultry hydrolyze rapidly after excretion to form NH_3). Because NH_3 is highly soluble in water, NH_3 accumulates in manures handled as liquids and semi-solids or slurries but volatizes rapidly with drying and from manures handled as solids. Therefore, the potential for NH_3 volatilization exists wherever manure is present and NH_3 is emitted from confinement buildings, open lots, stockpiles, anaerobic lagoons, and land application from both wet and dry handling systems.

The volatilization of NH_3 from any AFO operation can be highly variable depending on total NH_3 concentration, temperature, pH, and storage time. Emissions will depend on how much of the NH_3-nitrogen in solution reacts to form NH_3 versus ionized ammonium (NH_4^+), which is nonvolatile. In solution, the partitioning of NH_3 between the ionized (NH_4^+) and un-ionized (NH_3) species is controlled by pH and temperature. Under acidic conditions (pH values of less than 7.0) ammonium is the dominant species, and NH_3 volatilization occurs at a lower rate than at higher pH values. However, some NH_3 volatilization occurs even under moderately acidic conditions. Under acidic conditions, NH_3 that is volatized will be replenished due to the continual re-establishment of the equilibrium between the concentrations of the ionized and un-ionized species of NH_3 in solution following volatilization. As pH increases above 7.0, the concentration of NH_3 increases as does the rate of NH_3 volatilization. The pH of manures handled as solids can be in the range of 7.5 to 8.5, which results in fairly rapid NH_3 volatilization. Manure handled as liquids or semi-solids tend to have lower pH. Because of its high solubility in water, the loss of NH_3 to the atmosphere will be more rapid when drying of

manure occurs. However, there may be little difference in total NH_3 emissions between solid and liquid manure handling systems if liquid manure is stored over extended periods of time prior to land application.

9.4.3.1.2 Hydrogen Sulfide

Microbial decomposition of sulfur contained in manure under anaerobic conditions produces H_2S and other reduced sulfur compounds (e.g., methyl mercaptan, dimethyl sulfide, dimethyl disulfide, and carbonyl sulfide). The sources of sulfur in animal manures are: (1) amino acids contained in the feed, (2) inorganic sulfur compounds (e.g., copper sulfate, zinc sulfate) used as feed additives to supply trace minerals and serve as growth stimulants, and (3) trace minerals in drinking water.

Manures managed as liquids or slurries are potential sources of H_2S emissions due to the anaerobic microbial environment. The magnitude of H_2S emissions is a function of liquid phase concentration, temperature, and pH. Temperature and pH affect the solubility of H_2S in water. The solubility of H_2S in water increases at pH values above 7. Therefore, the potential for H_2S emissions increases as the pH shifts from alkaline to acidic (pH < 7). Under anaerobic conditions, livestock and poultry manures will be acidic with pH values ranging from 5.5 to 6.5. At AFOs that handle manure in a dry form, the reduced sulfur compounds in manure are oxidized microbially to nonvolatile sulfate, and emissions of H_2S are minimal.

9.4.3.1.3 Volatile Organic Compounds

Volatile organic compounds form as intermediate metabolites in the degradation of organic matter in manure. Under aerobic conditions, any VOC formed are rapidly oxidized to carbon dioxide and water. Under anaerobic conditions, complex organic compounds are degraded microbially to volatile organic acids and other VOCs, which in turn are converted to methane and carbon dioxide by methanogenic bacteria. When the activity of the methanogenic bacteria is not inhibited, virtually all of the VOC are metabolized to simpler compounds, and the potential for VOC emissions is nominal. However, the inhibition of methane formation results in a buildup of VOC in the manure and ultimate volatilization to the air. Inhibition of methane formation typically is caused by low temperatures or excessive loading rates of volatile solids in a liquid storage facility. Both of these conditions create an imbalance between populations of the microorganisms responsible for the formation of VOC and methanogenic bacteria. Therefore, VOC emissions will be minimal from properly designed and operated stabilization processes (such as anaerobic lagoons) and the associated manure application site. In contrast, VOC emissions will be higher from storage tanks, ponds, overloaded anaerobic lagoons, silage piles, and associated land application sites. The specific VOC emitted will vary depending on the solubility of individual compounds and other factors (including temperature) that affect solubility.

9.4.3.2 Particulates

The primary mechanism for direct releases of PM from AFOs is the entrainment of feeds, dry manure, soil, and other material (e.g., bedding materials, dander, feathers) caused by movement of animals in both indoor and outdoor confinement and activity at land application sites. The relative significance of each source depends on three interrelated factors: (1) the type

of animal being raised, (2) the design of the confinement facility being utilized, and (3) the method of manure handling (wet or dry). Additionally, precursors (e.g., NH_3 from AFOs and sulfur or nitrogen oxides) in the atmosphere can be converted to secondary particulate such as ammonium sulfate or ammonium nitrate.

Although all confinement facilities are sources of PM emissions, the composition of PM emissions varies with the only constant constituent being animal dander and feather particles from poultry. For poultry and swine, feed particles constitute a significant fraction of PM emissions because the dry, ground feed grains and other ingredients used to formulate these feeds are inherently dusty. Pelletizing of feeds reduces, but does not eliminate, dust and PM emissions. Dried forages also generate PM, but most likely to a lesser degree. Silages, which have relatively high moisture content, tend to generate less PM than for other types of feed. Because veal calves are fed a liquid diet, feed does not contribute to particle emissions from veal operations. The mass of PM emitted from totally or partially enclosed confinement facilities, as well as the particle size distribution, depend on the type of ventilation and ventilation rate. Particulate matter emissions from naturally-ventilated (NV) buildings will be lower than those from mechanically-ventilated (MV) buildings. Mechanically-ventilated buildings will emit more PM at higher ventilation rates. Therefore, confinement facilities located in warmer climates will tend to emit more PM because of the higher ventilation rates needed for cooling. While confinement facilities for dairy and beef cattle typically are all naturally ventilated, facilities for poultry, swine, and veal are mechanically ventilated for all or at least part of the year. When mechanical ventilation is used for only part of the year, it is used during the coldest and hottest months with natural ventilation used during the remainder of the year.

Open feedlots and storage facilities for dry manure from broilers, turkeys, laying hens in high rise houses, dairy drylots, and beef cattle drylots also are potential sources of PM emissions. The rate of emission depends on whether or not the manure is covered. Open sites are intermittent sources of PM emissions, because of the variable nature of wind direction and speed and precipitation. Thus, the moisture content of the manure and the resulting emissions will be highly variable. The PM emissions from covered manure storage facilities depend on the degree of exposure to wind.

9.4.4 Emissions Calculations and Correction Parameters

For broiler, layer, swine, and dairy operations, the EPA developed the emissions estimating methodologies (EEMs) based on analysis of the environmental, process, and emissions data collected under the National Air Emissions Monitoring Study (NAEMS). The supporting documentation for the EEMs provide an overview of the available data and the development procedures[1] and the specific analysis conducted for each animal sector.[15, 16, 17, 18] The sector-specific reports provided example calculations using the EEMs. In general, the EPA prepared the NAEMS dataset for subsequent analysis and compared and contrasted the datasets available for monitoring sites within each animal type and process (e.g., swine MV barn) and to identify emissions patterns and process differences that might influence emissions, and to identify the strength of relationships between the available process parameters, environmental conditions, and emissions. Next, the EPA performed literature

reviews to identify parameters that have established relationships with emissions and to conducted exploratory data analysis to assess the strength of these well-established relationships within the NAEMS datasets and to characterize the quantity of data available and the potential availability of the parameters to a typical producer. After selecting the parameters for use as equation variables, the EPA used an iterative process to develop daily models using varying combinations of variables and compare each combination using model fit and evaluation statistics and residual plots. After selecting the final models for each animal type and process, the EPA conducted additional validation using a jackknife approach, which evaluated the model variables for consistency and helped to identify whether a particular monitoring site strongly influenced model performance. For each of the resulting models, the EPA developed equations for assessing the uncertainty associated with annual emissions estimates for individual processes (e.g., swine MV barn) and for the overall AFO.

For VOC emissions from broiler, layer, swine, and dairy operations, the EPA developed emissions factors (e.g., g NH_3/d-head) based on information and emissions data collected through literature search and review activities.[19]

9.4.4.1 Broiler, Layer, Swine, and Dairy Operations

Tables 9.4-2, 9.4-3, 9.4-4, and 9.4-5 present the models, back-transform parameters, and uncertainty constants (relative standard deviation of residuals values for each model) for estimating pollutant emissions from broiler, layer, swine, and dairy operations, respectively. The tables also present the units of the emissions values obtained from using the models (e.g., kg/d, kg/m^2-d). Table 9.4-6 presents the definitions for the variables used in the emission models.

The models presented in Tables 9.4-2 through 9.4-5 provide daily emissions estimates (e.g., g/d). However, with the exception of the PM_{10}, $PM_{2.5}$, and total suspended particulate (TSP) models for broiler houses, the calculation results of the models presented in Table 9.4-2 through 9.4-5 provide log transformed values that must be back transformed using the Equation 1 to obtain results in the original emissions units:

$$Y_{bp} = e^{\widehat{(y_p)}} * \overline{E_i} - C \qquad \text{Equation 1}$$

Where:

Y_{bp} = estimated pollutant emissions (e.g., kg/d, kg/m^2d).

y_p = the log transformed value calculated using the AFO model.

$\overline{E_i}$ = the average residual between model-predicted and observed (or measured) emissions on the natural log scale, specified in Tables 9.4-2, 9.4-3, 9.4-4, or 9.4-5.
C = a constant added to the data prior to the log transformation, specified in Tables 9.4-2, 9.4-3, 9.4-4, or 9.4-5.

The height of wind speed measurements influences the observation as friction with the surface affects the observation. That is, the closer to the ground the measurement is made, the more friction will act to slow the speed. NAEMS winds were monitored at a height of approximately 2.5 meters (m) at swine open sources, while the National Weather Service (NWS) sites archived at the National Center for Environmental Information (NCEI) are typically monitored at 10 m. Therefore, the difference in measurement heights between NAEMS and NWS requires an adjustment to the wind speed values used in the daily emissions models. The relationship between wind speed and height is well established and can be written as:

$$\frac{V}{V_r} = \left(\frac{Z}{Z_r}\right)^m \qquad \text{Equation 2}$$

Where V_r is the wind velocity at a height of 10 m (Z_r) and V is the wind velocity height at 2.5 m (Z), and m is the friction coefficient, which is a function of atmospheric stability and the underlying surface roughness. The value of m can vary, ranging from 0 to 1, with lower values over low roughness surfaces (water) and higher values for rougher terrain such as rolling terrain or urban settings.[20] To adjust the 10-m NWS wind measurement to a height comparable to the study data used to develop the model, Equation 2 can be rewritten as follows:

$$V_{2.5m} = \left(\frac{2.5}{10}\right)^m \times V_{10m} \qquad \text{Equation 1}$$

For example, applying the wind speed correction to the NH_3 model for NV barns in Table 9.4-5, using an assume m value of 0.25, becomes:

$$ln(NH_3) = 0.188357 + 3.451939 * Inventory + 0.048153 * WindSpeed * 0.707107 \qquad \text{Equation 4}$$

Table 9.4-2. EMISSIONS MODELS FOR BROILER HOUSE OPERATIONS[15]

Pollutant	Model	$\overline{E_i}$	C	Sr	Emission Units[a]
NH_3	$ln(NH_3) = 1.60581 + 0.008532 * LAW + 0.020739 * Amb_T + 0.004038 * Amb_{RH}$	1.10605	2	7.205	kg/d
H_2S	$ln(H_2S) = 2.824278 + 0.016214 * LAW + 0.015048 * Amb_T + 0.004429 * Amb_{RH}$	1.32433	10	36.749	g/d
PM_{10}	$PM_{10} = 397.28057 + 40.872002 * LAW + 10.401892 * Amb_T - 6.584463 * Amb_{RH}$	NA	NA	414.19	g/d
$PM_{2.5}$	$PM_{2.5} = 15.776704 + 4.087002 * LAW + 1.308433 * Amb_T - 0.464143 * Amb_{RH}$	NA	NA	36.703	g/d
TSP	$TSP = 1518.9199 + 85.598315 * LAW + 22.632906 * Amb_T - 21.28833 * Amb_{RH}$	NA	NA	1,304	g/d

[a] kg/d is kilogram per day; g/d is gram per day.

Table 9.4-3. EMISSIONS MODELS FOR LAYER OPERATIONS[16]

Process	Pollutant	Model	$\overline{E_i}$	C	Sr	Emission Units[a]
High-rise House	NH_3	$ln(NH_3) = 2.6598 + 0.0059 * Inventory + 0.0387 * Amb_T + 0.0018 * Amb_{RH}$	1.58238	0	87.746	kg/d
High-rise House	H_2S	$ln(H_2S) = 2.7231 + 0.0098 * Inventory + 0.0210 * Amb_T + 0.0038 * Amb_{RH}$	1.24359	15	121.035	g/d
High-rise House	PM_{10}	$ln(PM_{10}) = 6.8702 + 0.0077 * Inventory + 0.0145 * Amb_T - 0.0030 * Amb_{RH}$	1.11745	494	2,041.8	g/d
High-rise House	$PM_{2.5}$	$ln(PM_{2.5}) = 4.6219 + 0.0080 * Inventory + 0.0510 * Amb_T - 0.0181 * Amb_{RH}$	1.51089	37	286.63	g/d
High-rise House	TSP	$ln(TSP) = 7.5995 + 0.0079 * Inventory + 0.0137 * Amb_T - 0.0058 * Amb_{RH}$	1.11429	0	2,235.6	g/d
Manure belt	NH_3	$ln(NH_3) = 2.4392 + 0.0047 * Inventory + 0.0294 * Amb_T + 0.0019 * Amb_{RH}$	1.27315	0	49.882	kg/d
Manure belt	H_2S	$ln(H_2S) = 3.7391 + 0.0073 * Inventory + 0.0222 * Amb_T + 0.0048 * Amb_{RH}$	1.09812	39	246.84	g/d
Manure belt	PM_{10}	$ln(PM_{10}) = 6.631005 + 0.007205 * Inventory$	1.45218	1045	7,074.6	g/d
Manure belt	$PM_{2.5}$	$ln(PM_{2.5}) = -127.4489 + 0.534577 * Inventory$	2.97703	108	532.71	g/d
Manure belt	TSP	$ln(TSP) = 6.936206 + 0.00987 * Inventory$	1.34146	696	17,593	g/d
Manure shed	NH_3	$ln(NH_3) = -0.194945 + 0.003927 * Inventory\ (5\ day\ lag) - 0.013752 * Amb_T$	1.28615	1.3	6.375	kg/d
Manure shed	H_2S	$ln(H_2S) = 1.295775 + 0.004976 * Inventory\ (5\ day\ lag) - 0.024164 * Amb_T$	1.36619	6.0	48.086	g/d
Manure shed	PM_{10}	$ln(PM_{10}) = 4.5366 + 0.000732 * Inventory\ (5\ day\ lag)$	1.68902	54.0	294.28	g/d

Process	Pollutant	Model	$\overline{E_t}$	C	Sr	Emission Units[a]
Manure shed	$PM_{2.5}$	$ln(PM_{2.5}) = -30.57734 + 0.067599 * Inventory\ (5\ day\ lag)$	1.68697	0.0	63.568	g/d
Manure shed	TSP	$ln(TSP) = 4.041666 + 0.002286 * Inventory\ (5\ day\ lag)$	2.01361	30.0	408.580	g/d

[a] kg/d is kilogram per day; g/d is gram per day.

Table 9.4-4. EMISSIONS MODELS FOR SWINE OPERATIONS[17]

Process	Pollutant	Model	$\overline{E_t}$	C	Sr	Emission Units[a]
Farrowing barn	NH_3	$ln(NH_3) = 0.6888 + 0.0020 * cycleday + 0.0006 * Amb_T + 0.0084 * LAW$	1.06677	0	0.199	kg/d-room
Farrowing barn	H_2S	$ln(H_2S) = 2.1423 + 0.1298 * cycleday + 0.0614 * LAW$	1.4588	3	111.4	g/d-room
Farrowing barn	PM_{10}	$ln(PM_{10}) = 2.490 + 0.0558 * cycleday + 0.1063 * LAW - 0.0034 * Amb_{RH}$	1.05116	2	18.299	g/d-room
Farrowing barn	$PM_{2.5}$	$ln(PM_{2.5}) = -1.2146 + 0.0759 * cycleday + 0.2564 * LAW$	0.86487	6	2.609	g/d-room
Farrowing barn	TSP	$ln(TSP) = 2.8589 + 0.0706 * cycleday + 0.1473 * LAW - 0.0049 * Amb_{RH}$	1.17091	0	53.848	g/d-room
Gestation barn, no pit	NH_3	$ln(y_p) = 0.7844 + 0.0056 * Amb_T + 0.0073 * LAW$	1.2156	0	10.346	kg/d
Gestation barn, no pit	H_2S	$ln(H_2S) = 2.0773 + 0.0035 * Amb_T + 0.0199 * LAW$	2.1131	29	3,292	g/d
Gestation barn, no pit	PM_{10}	$ln(PM_{10}) = 5.1868 - 0.0078 * Amb_{RH} + 0.0055 * LAW$	1.09772	0	182.57	g/d
Gestation barn, no pit	$PM_{2.5}$	$ln(PM_{2.5}) = 4.88715 + 0.0007 * LAW$	1.01188	114	22.211	g/d
Gestation barn, no pit	TSP	$ln(TSP) = 5.53397 + 0.0080 * Amb_{RH} + 0.0066 * LAW$	1.02075	0	351.87	g/d
Gestation barn, shallow pit	NH_3	$ln(y_p) = 0.3075 + 0.0118 * Amb_T + 0.0079 * LAW$	1.06524	0	9.123	kg/d
Gestation barn, shallow pit	H_2S	$ln(H_2S) = 2.1305 + 0.0038 * Amb_T + 0.0196 * LAW$	1.28254	29	2,876	g/d
Gestation barn, shallow pit	PM_{10}	$ln(PM_{10}) = 5.1868 - 0.0078 * Amb_{RH} + 0.0055 * LAW$	1.09772	0	182.57	g/d
Gestation barn, shallow pit	$PM_{2.5}$	$ln(PM_{2.5}) = 4.88715 + 0.0007 * LAW$	1.01188	114	22.211	g/d
Gestation barn, shallow pit	TSP	$ln(TSP) = 5.53397 + 0.0080 * Amb_{RH} + 0.00066 * LAW$	1.02075	0	351.87	g/d
Gestation barn, deep pit	NH_3	$ln(y_p) = 0.8348 + 0.0118 * Amb_T + 0.0079 * LAW$	1.06524	0	9.123	kg/d
Gestation barn, deep pit	H_2S	$ln(H_2S) = 3.1785 + 0.0038 * Amb_T + 0.0196 * LAW$	1.28254	29	2,876	g/d
Gestation barn, deep pit	PM_{10}	$ln(PM_{10}) = 5.1868 - 0.0078 * Amb_{RH} + 0.0055 * LAW$	1.09772	0	182.57	g/d
Gestation barn, deep pit	$PM_{2.5}$	$ln(PM_{2.5}) = 4.88715 + 0.0007 * LAW$	1.01188	114	22.211	g/d
Gestation barn, deep pit	TSP	$ln(TSP) = 5.53397 + 0.0080 * Amb_{RH} + 0.00066 * LAW$	1.02075	0	351.87	g/d
Finishing barn, no pit	NH_3	$ln(NH_3) = 1.2363 + 0.00895 * Amb_T + 0.0089 * LAW$	1.04371	1	2.139	kg/d
Finishing barn, no pit	H_2S	$ln(H_2S) = 4.0820 - 0.0066 * Amb_T + 0.0172 * LAW$	2.37261	13	205.55	g/d
Finishing barn, no pit	PM_{10}	$ln(PM_{10}) = 5.5039 - 0.0094 * Amb_{RH} + 0.0104 * LAW$	1.05297	67	96.621	g/d
Finishing barn, no pit	$PM_{2.5}$	$ln(PM_{2.5}) = 2.4954 - 0.0023 * Amb_{RH} + 0.01095 * LAW$	1.08403	10	4.269	g/d

Process	Pollutant	Model	$\overline{E_i}$	C	Sr	Emission Units[a]
Finishing barn, no pit	TSP	$ln(TSP) = 6.266 - 0.0088 * Amb_{RH} + 0.0118 * LAW$	1.09602	0	229.25	g/d
Finishing barn, shallow pit	NH_3	$ln(y_p) = 1.1422 + 0.0091 * Amb_T + 0.0085 * LAW$	1.06222	1	2.088	kg/d
Finishing barn, shallow pit	H_2S	$ln(H_2S) = 4.1905 - 0.0055 * Amb_T + 0.0133 * LAW$	1.52598	13	246.73	g/d
Finishing barn, shallow pit	PM_{10}	$ln(PM_{10}) = 5.5039 - 0.0094 * Amb_{RH} + 0.0104 * LAW$	1.05297	67	96.621	g/d
Finishing barn, shallow pit	$PM_{2.5}$	$ln(PM_{2.5}) = 2.4954 - 0.0023 * Amb_{RH} + 0.01095 * LAW$	1.08403	10	4.269	g/d
Finishing barn, shallow pit	TSP	$ln(TSP) = 6.266 - 0.0088 * Amb_{RH} + 0.0118 * LAW$	1.09602	0	229.25	g/d
Finishing barn, deep pit	NH_3	$ln(y_p) = 1.3424 + 0.0091 * Amb_T + 0.0085 * LAW$	1.06222	1	2.088	kg/d
Finishing barn, deep pit	H_2S	$ln(H_2S) = 4.9916 + 0.0055 * Amb_T + 0.0133 * LAW$	1.52598	13	246.73	g/d
Finishing barn, deep pit	PM_{10}	$ln(PM_{10}) = 5.5039 - 0.0094 * Amb_{RH} + 0.0104 * LAW$	1.05297	67	96.621	g/d
Finishing barn, deep pit	$PM_{2.5}$	$ln(PM_{2.5}) = 2.4954 - 0.0023 * Amb_{RH} + 0.01095 * LAW$	1.08403	10	4.269	g/d
Finishing barn, deep pit	TSP	$ln(TSP) = 6.266 - 0.0088 * Amb_{RH} + 0.0118 * LAW$	1.09602	0	229.25	g/d
Gestation, lagoon	NH_3	$ln(NH_3) = 0.5821 + 0.0557 * Amb_T + 0.0914 * WindSpeed$	1.03459	2	2.517	g/m^2-d
Gestation, lagoon	H_2S	$ln(H_2S) = 4.6796 + 0.11516 * WindSpeed * 0.840896$	1.48373	100	605.67	mg/m^2-d
Finishing, lagoon	NH_3	$ln(NH_3) = -0.6801 + 0.0854 * Amb_T + 0.1319 * WindSpeed$	1.09967	0	3.903	g/m^2-d
Finishing, lagoon	H_2S	$ln(H_2S) = 3.6948 + 0.2790 * WindSpeed * 0.840896$	2.04143	7	379	mg/m^2-d
Basin	NH_3	$ln(NH_3) = 1.5049 + 0.01171 * Amb_T$	1.16858	2	0.008	g/m^2-d
Basin	H_2S	$ln(H_2S) = 0.4689 + 0.0270 * Amb_T$	1.1225	1	3.225	g/m^2-d

[a] kg/d is kilogram per day; g/d is gram per day; kg/d-room is kilogram per day by room; g/d-room is gram per day by room; g/m^2-d is gram per meter squared day; mg/m^2-d is milligram per meter squared day.

Table 9.4-5. EMISSIONS MODELS FOR DAIRY OPERATIONS[18]

Process	Pollutant	Model	$\overline{E_i}$	C	Sr	Emission Units[a]
MV barn w/manure flushing	NH_3	$ln(NH_3) = 1.746585 + 1.773832 * Inventory + 0.029586 * Amb_T$	1.03966	3	9.393	kg/d
MV barn w/manure flushing	H_2S	$ln(H_2S) = 7.406887 + 0.86173 * Inventory + 0.012786 * Amb_T$	1.11434	628	921.07	g/d
MV barn w/manure scraping	NH_3	$ln(NH_3) = 1.864935 + 1.773832 * Inventory + 0.029586 * Amb_T$	1.03966	3	9.393	kg/d
MV barn w/manure scraping	H_2S	$ln(H_2S) = 6.287004 + 0.86173 * Inventory + 0.012786 * Amb_T$	1.11434	628	921.07	g/d
MV barn	PM10	$ln(PM_{10}) = 8.130759 + 0.01083 * Amb_T - 0.00432 * Amb_{RH}$	1.11762	2200	473.12	mg/d-hd
MV barn	PM2.5	$ln(PM_{2.5}) = 6.76777 + 0.00474 * Amb_T - 0.00055 * Amb_{RH}$	1.13872	680	866.66	mg/d-hd
MV barn	TSP	$ln(TSP) = 8.434953 + 0.01277 * Amb_T - 0.01342 * Amb_{RH}$	1.32911	978	5,798.5	mg/d-hd
NV barn	NH_3	$ln(NH_3) = 0.188357 + 3.451939 * Inventory + 0.048153 * WindSpeed * 0.707107$	1.46499	3	19.759	kg/d
NV barn	H_2S	$ln(H_2S) = 6.541057 + 0.587702 * Inventory + 0.062678 * WindSpeed$	1.23366	628	1,331.3	g/d
NV barn	PM_{10}	$ln(PM_{10}) = 7.64258 + 1.525009 * Inventory + 0.011864 * Amb_T - 0.01521 * Amb_{RH} + 0.173698 * WindSpeed$	1.27211	2200	15,938	g/d
NV barn	$PM_{2.5}$	$ln(PM_{2.5}) = 7.068797 - 0.220453 * Inventory + 0.01121 * Amb_T - 0.003808 * Amb_{RH} + 0.218968 * WindSpeed$	1.33005	680	1,382.2	g/d
NV barn	TSP	$ln(TSP) = 7.868847 + 2.953893 * Inventory + 0.034508 * Amb_T - 0.033997 * Amb_{RH} + 0.248191 * WindSpeed$	1.25126	978	22,252	g/d
Milking center	NH_3	$ln(NH_3) = 2.505637 + 0.046434 * Amb_T$	1.21693	3	14.823	g/d-hd
Milking center	H_2S	$ln(H_2S) = 6.898188 + 0.024053 * Amb_T$	1.30119	628	2,507.8	mg/d-hd
Milking center	PM_{10}	$ln(PM_{10}) = 8.042215 + 0.006791 * Amb_T - 0.003552 * Amb_{RH}$	1.0057	2200	289.09	mg/d-hd
Milking center	$PM_{2.5}$	$ln(PM_{2.5}) = 6.58377 + 0.006698 * Amb_T$	1.00796	680	132.7	mg/d-hd
Milking center	TSP	$ln(TSP) = 7.457268 + 0.010997 * Amb_T - 0.003639 * Amb_{RH}$	1.0311	978	416.02	mg/d-hd
Lagoon	NH_3	$ln(H_2S) = 1.189272 + 0.010557 * Amb_T$	1.03006	3	0.001	g/d-m^2
Lagoon	H_2S	$ln(NH_3) = 1.396734 + 0.027201 * Amb_T$	1.0079	3	0.700	g/d-m^2
Corral	NH_3	$ln(NH_3) = 1.053805 + 0.004993 * Amb_T + 0.0031 * Amb_{RH} + 0.017832 * WindSpeed$	1.0066	3	1.276	mg/d-m^2-hd
Corral	H_2S	$ln(H_2S) = 2.404792 + 0.007177 * Amb_{RH}$	1.00007	3	18.451	µg/d-m^2-hd

[a] kg/d is kilogram per day; g/d is gram per day; g/d-hd is gram per day of the total head milked; mg/d-hd is milligram per day of the total head milked; g/d-m^2 is gram per day square meter; mg/m^2-d is milligram per square meter day; mg/d-m^2-hd is milligram per day square meter of the total head milked; µg/d-m^2-hd is microgram per day square meter of the total head milked.

Table 9.4-6. EMISSIONS MODEL VARIABLE DEFINITIONS

Variable	Definition
Amb_T	Ambient (°C)
Amb_{RH}	Ambient relative humidity (%)
cycleday	The day of the animal placement cycle (e.g., the day the sow is moved to the barn is cycle day 1)
Inventory	Layers = 1,000 birds Dairy = 1,000 head
Inventory (5-day lag)	5-day lag of inventory for layer manure sheds
LAW	Live animal weight (Mg) for broilers and swine = avg animal mass * no. of animals
WindSpeed	Wind speed (m/s)

The EPA also developed an estimate of uncertainty for total annual emissions, characterized by the random error in the model prediction, based on parametric principles, using the Gaussian error of propagation. Under this approach, the annual standard deviation (S_{an}) for n days can be determined using the following equation:

$$S_{an} = \sqrt{(S_{r1})^2 + (S_{r2})^2 + \ldots (S_{rn})^2} \quad \text{Equation 5}$$

where S_r is the standard deviation of the daily residual values (i.e., the difference between model-predicted and observed or measured emissions). If S_r is the same value for each day (i.e., $S_{r1} = S_{r2} = S_{rn}$), Equation 5 simplifies to:

$$S_{an} = S_r n \quad \text{Equation 6}$$

Tables 9.4-2 through 9.4-5 present the S_r values by process and pollutant.

To propagate the uncertainty across all sources at a farm, the estimates of absolute uncertainty for each source are combined according to:

$$Total\ farm\ uncertainty = \sqrt{(U_{B1})^2 + \cdots + (U_{Bi})^2} \quad \text{Equation 7}$$

Where:

Total farm uncertainty = total uncertainty for the total emissions from all farm sources.

UBi = the resulting uncertainty for barns, with i representing the total number of barns on the farm.

ULj = the resulting uncertainty for manure sheds, with j representing the total number of open sources on the farm.

The uncertainty framework described above reflects the random uncertainty (error) in the prediction of daily emissions calculated using the emission models, which includes the random uncertainty in the measurements used to develop the equation. This framework does not, however, consider systematic error (e.g., bias) in either NAEMS measurements or the emission model.

9.4.4.2 Emissions Factors

Although the NAEMS is one of the most comprehensive AFO monitoring studies conducted to date, the VOC data collected under the NAEMS do not have the quality and quantity necessary to develop a total VOC EEMs using a similar statistical modeling process utilized for the other pollutants. Consequently, EPA developed emissions factors (presented in Table 9.4-7) using the NAEMS data, where available, and data and information identified from EPA literature reviews. The factors shown in Table 9.4-7 represent uncontrolled emissions.

Table 9.4-7. AFO EMISSIONS FACTORS

Animal	Process	Pollutant	Emissions Factor (g/d-hd)	Reference
Broiler	High-rise house (mechanically ventilated)	VOC	0.108	19
Layer	High-rise house (mechanically ventilated)	VOC	0.121	19
Layer	Manure belt house (mechanically ventilated)	VOC	0.037	19
Dairy	Barn (mechanically ventilated)	VOC	16.222	19
Dairy	Barn (naturally ventilated)	VOC	9.10	19
Dairy	Milking center (mechanically ventilated)	VOC	1.718	19
Swine	Farrowing room	VOC	5.244	19
Swine	Gestation barn (mechanically ventilated)	VOC	4.284	19
Swine	Gestation barn (mechanically ventilated)	VOC	2.593	19

9.4.5 Emissions Mitigation and Controls[2, 21]

As discussed in section 9.4.8.1 of this document, gaseous pollutants (NH_3, H_2S, and VOC) originate from the microbial degradation of manure, with NH_3 and VOC forming under aerobic and anaerobic conditions and H_2S forming only under anaerobic conditions. After formation, which begins immediately upon excretion, the gaseous pollutants volatilize from manure handled in the animal confinement; manure storage and stabilization; and the land application processes with the presence of chemical precursors and favorable environmental conditions (e.g., anaerobic conditions) dictating the rate of pollutant emissions. Particulate emissions primarily originate due to entrainment of feeds, dry manure, soil, and other low-moisture materials caused by animal and vehicle activity. Also, secondary particulate (e.g., ammonium sulfate or ammonium nitrate) can form in the atmosphere due to chemical interactions of precursor emissions (e.g., NH_3) from AFOs and sulfur or nitrogen oxides present in the atmosphere.

Operators can minimize pollutant emissions from AFO process units that handle or store manure (e.g., broiler house, dairy anaerobic lagoon) by using formation inhibition and

emissions suppression techniques. Inhibition techniques either reduce the availability of chemical precursors (e.g., nitrogen for NH_3 formation) or environmental conditions (low moisture content of feedlot surfaces) that favor formation, while suppression techniques curtail the release of pollutants after formation. However, because these techniques do not physically alter or destroy pollutants, the emissions can be delayed or transferred to other downstream AFO processes, if the precursors and/or environmental conditions exist (e.g., NH_3 emissions reduced by a lagoon cover are released during surface application of the manure at the disposal site). Additionally, inhibition and suppression techniques can reduce emissions of one pollutant, but increase emissions of another pollutant. For example, feeding calcium sulfate to laying hens increases the pH of the excreted manure, which reduces NH_3 formation, but also increases the amount of sulfur available to form H_2S.

Operators can also use control techniques (e.g., ESP in confinement house, direct injection of manure at the land application site) to reduce the amount of pollutants emitted from AFO processes.

Table 9.4-8 summarizes the potentially applicable emissions reduction measures by AFO process and pollutant.

TABLE 9.4-8. SUMMARY OF INHIBITION, SUPPRESSION, AND CONTROL TECHNIQUES FOR AFOS

Technique	Description	Confinement	Storage	Disposal
Inhibition	Diet manipulation	NH_3, H_2S, VOC, PM	NH_3, H_2S, VOC, PM	NH_3, H_2S, VOC, PM
Inhibition	Manure amendments and additives	NH_3, H_2S, VOC	NH_3, H_2S, VOC	NH_3, H_2S, VOC
Inhibition	Process design, modifications, and operations	NH_3, H_2S, VOC, PM	NH_3, H_2S, VOC, PM	NH_3, H_2S, VOC, PM
Suppression	Water sprays	PM	Not applicable (NA)	NA
Suppression	Oil sprays	PM	NA	NA
Suppression	Covers	NA	NH_3, H_2S, VOC, PM	NA
Control	Filtration (inertial)	PM	NA	NA
Control	Wet scrubbing	PM	NA	NA
Control	Gas absorption	NH_3, H_2S, VOC	NA	NA
Control	Ozonation	NH_3, H_2S, VOC	NH_3, H_2S, VOC	NA
Control	Ionization and electrostatic precipitation	PM	NA	NA
Control	Chemical oxidation	NH_3, H_2S, VOC	NA	NA
Control	Biofiltration	NH_3, H_2S, VOC, PM	NA	NA
Control	Bioscrubbing	NH_3, H_2S, VOC, PM	NA	NA
Control	Covers with biogas control	NA	NH_3, H_2S, VOC	NA
Control	Anaerobic digestion with biogas control	NA	NH_3, H_2S, VOC	NA
Control	Biocovers for liquid manure storage	NA	NH_3, H_2S, VOC	NA
Control	Incorporation of land-applied manure	NA	NA	NH_3, H_2S, VOC
Control	Thermo-chemical treatment	NA	NA	NH_3, H_2S, VOC

9.4.5.1 Inhibition Techniques[2, 21]

Diet manipulation

Diet manipulation has the potential to reduce PM gaseous pollutant emissions from AFO processes that generate or handle manure through:

- Feeding practices.
- Optimizing feed formulations.
- Using feed additives.

Because animals of different ages and sexes have different growth rates and nutrient requirements, operators can employ group and phase feeding practices to provide diets that more closely match the different nutritional needs of each growth phase and sex to avoid providing excess nutrients in diets and subsequent manure excretions.

Optimizing the amount of protein, sulfur, and other nutrients contained in dietary formulations can reduce the amount of chemical precursors in excreted manure (e.g., reducing dietary crude protein intake can reduce the nitrogen content in the excreted manure, which reduces the potential for NH_3 formation). In animal diets, protein provides amino acids needed for growth, reproduction and milk or egg production. However, lowering the crude protein content can cause deficiency in certain amino acids that significantly affect animal performance. Therefore, operators can add supplemental synthetic amino acids (e.g., (synthetic lysine, methionine, threonine and tryptophan) in feed rations that have lower crude protein content.

Manure Amendments and Additives

The purpose of manure amendments and additives is to change the manure properties to reduce pollutant formation and subsequent volatilization. The additives include adsorbents, microbial organisms and enzymes, and chemical acidifiers. Adsorbents (e.g., zeolite, sphagnum moss) have large surface areas which physically or chemically bind gaseous pollutants, preventing their volatilization. Microorganisms and/or enzymes added to the manure systems reduce emissions of NH_3, H_2S, and VOC by breaking down organic compounds.

Acidification is used extensively to reduce NH_3 emissions during the initial stage of broiler and turkey grow-out cycles to decrease the incidence of NH_3-induced respiratory problems and blindness in young birds. Due to concerns regarding high phosphorus concentrations in land-applied manures, the use of phosphoric acid as the acidifying agent has changed to using other materials, such as sodium bisulfate and aluminum sulfate. Typically, acidification inhibits NH_3 volatilization for approximately two weeks after application of the acidifying agent, due to buffering agents, such as calcium and magnesium carbonates, being continually added in freshly excreted manure. Acidification is also applicable to manure collection in confinement housing for swine and dairy operations that use flushing systems, since using a low-pH flushing liquid can decrease the rate of NH_3 formation and volatilization in the house. Acidifying slurry manure is not used as frequently because there is a potential that it will increase the generation of H_2S.

Process design, modifications, and operations

Confinement facility design and operating practices can inhibit the generation of reduced gaseous compounds or suppress emissions once they have been generated. However, suppression techniques may only transfer the point of emissions to another AFO process (e.g., to manure storage or a land application site). Also, because of their nature, these design and operating practices may be applicable only to new facilities.

On outdoor feedlots, moist conditions lead to anaerobic decomposition of manure. Suppression of emissions of reduced gaseous compounds can be achieved by faster drying of manure and frequent removal of manure from the confinement area. Sloping of the feedlot surface (4 to 6 percent) towards the south to southeast direction will ensure that the feedlot will receive the most insolation and that the accumulated manure dries more quickly. Ammonia and other gaseous emissions can also be reduced by removing solid manure frequently (every 7 days or less). However, manual removal will tend to transfer NH_3 and other gaseous emissions to manure storage and stabilization processes. With slurry systems, frequent flushing or scraping to remove manure from partially or totally enclosed facilities also reduces the potential for gaseous compound emissions from the confinement facility. A smooth floor surface will increase the effectiveness of frequent removal by both flushing and scraping. Ideas such as flow-through partitions and under floor ventilation have been proposed to enhance manure drying in partially or totally enclosed confinement facilities but both effectiveness and practicality seem questionable.

In facilities were manure is collected in shallow or deep pits, which typically are located under slatted floors, filling the pit with enough water so that all of the accumulating manure solids are submerged may reduce NH_3, H_2S, and VOC emissions to some degree. Both NH_3 and H_2S are highly soluble in water as are some VOC. If these pits are not ventilated and have little natural air movement, there will be a decrease in the concentration gradient across the interface between the liquid and gas phases with the consequence of decreased rates of mass transfer. Because methane is essentially insoluble in water, methane emissions will not be decreased.

9.4.5.2 Suppression Techniques

Water Sprays

To suppress PM emissions from outdoor feedlots, operators can use water sprays from tanker trucks or sprinkler systems to prevent the confinement surface area (e.g., manure and soil) from becoming too dry. For indoor operations, increasing the humidity level of building air (e.g., using misting systems for evaporative cooling) can reduce the indoor concentration of suspended PM. However, increasing the moisture content of outdoor confinement soil or litter in broiler and turkey production facilities may increase other emissions because microbial activity in the manure is stimulated.

Oil Sprays

Suppression of PM from confinement housing has been achieved by applying vegetable oil on interior building surfaces (e.g., using hand-held sprayers or sprinklers systems) and by

applying oil to the skin of swine (using rollers or scratching posts that dispense oil on contact) can suppress PM emissions from confinement housing. However, the oil can be a safety hazard (i.e., slippery floors) for both personnel and animals. Also, the oily surfaces can increase building clean-out times between production cycles and may contribute to the formation of gaseous pollutants due to microbial decomposition.

Covering of Manure Storage and Treatment Processes

Air circulation over the manure surface in storage and treatment processes can entrain PM from processes that handle manure as a solid (e.g., poultry and beef operations) and increase volatilization of gaseous pollutants from processes that handle manure as a liquid or slurry (e.g., swine operations) by reducing the concentration at the air/water interface, which increases the diffusion of pollutants from liquid to air. Covering manure storage and treatment process units will suppress pollutant emissions; however, the degree of suppression depends on how well the cover deflects air circulation and the impermeability of the cover to diffusion and volatilization of gaseous pollutants (e.g., displacement by wind or channeling of gases through holes or cracks decreases the effectiveness of the cover).

For storage and treatment processes that handle manure as a solid, limiting the air flow over manure stockpiles by using windbreak walls, covers (e.g., plastic sheeting or tarpaulins), or enclosed buildings will reduce PM emissions from these processes. For liquid manure storage tanks, ponds, and anaerobic lagoons, covers for suppressing volatilization of gaseous pollutants can be self-supporting or can float directly on the manure surface. Generally, self-supporting covers are made from materials such as wood, plastic, and concrete and may require a drainage system to prevent damage caused by the weight of accumulated precipitation. Floating covers can be permanent (e.g., polymer sheeting, polystyrene blocks) or temporary (e.g., surface crust, straw). Because they are typically attached to the tank or lagoon perimeter, permanent floating covers are less likely to be affected by wind than temporary floating covers. However, attached covers may not be applicable to cases where the level of the manure surface fluctuates appreciably. Similar to self-supporting covers, permanent floating covers made from continuous materials (e.g., plastic sheeting) may require a drainage system for removing accumulated precipitation. Temporary floating covers include the crust the can form naturally on the manure surface in some cases and application of surface materials (e.g., chopped straw, barley). Temporary covers can be disturbed by weather conditions (e.g., high winds), thereby reducing their effectiveness, and can require periodic re-application (e.g., to replace saturated covering materials that sink into the stored manure).

Incorporation of Land-Applied Manure

Most animal manure is disposed of through land application using tractor- or truck-mounted equipment. Following land application, incorporating manure below the soil surface reduces exposure of the manure to the atmosphere and provides the opportunity for the manure to be soil microorganisms to oxidize NH_3, H_2S, and VOC in the manure to nitrates, sulfates, carbon dioxide, and water. In general, a technique that applies and incorporates the manure in a single step will have lower emissions than a technique that requires several steps. For example, applying manure using direct injection methods will reduce emissions when

compared to band spreading followed by disking or plowing, since direct injection applies and covers the manure in a single pass of the machinery.

Manures in solid form are typically applied to the land surface using broadcast spreaders, although subsurface application of solid manure is a developing technique. In surface applications, incorporating the manure below the soil surface can significantly reduce gaseous pollutant emissions, if the manure is incorporated using disc harrowing, plowing, or similar techniques as soon as possible (i.e., within 24 hours) following initial application. However, the application and incorporation processes can generate PM emissions by entrain dry manure and soil particles. Reducing the number of passes needed for the machinery can decrease PM emissions. Also, suppression of PM emissions during and after land application of dry manure could be achieved by either increasing manure moisture content before spreading or by using water sprays during or after spreading or both. However, increasing moisture content before spreading would require thorough mixing to insure uniform moisture distribution and the volume of water required for water sprays would likely be prohibitive; although, a minimal degree of irrigation during and after spreading is a seemingly feasible option if sprinkler irrigation is available. Another feasible option is to avoid spreading of dry manure during windy conditions to reduce entrainment of PM.

Liquid and slurry manures can be applied to the soil surface using broadcast or hose spreaders; however, these manures can also be injected below the soil surface. As with solid manures, incorporating surface-applied liquid or slurry manures can reduce gaseous pollutant emissions; however, due to the greater potential for pollutant volatilization from these manures, incorporation must occur within one to two hours following initial application to achieve the greatest reduction in emissions.

9.4.5.3 Control Techniques

Filtration (inertial)

Filtration removes PM by impaction of entrained particulates as air passes through the filter media (inertial filters do reduce gaseous emissions). Filtration of indoor air can reduce PM emissions from confinement housing; however, filters are not feasible for outdoor confinement since the contaminated air cannot practically be captured and conveyed to the control device. Filtration can be applied to the exhaust air of mechanically-ventilated confinement buildings to reduce PM emissions from totally or partially enclosed confinement housing. Filters also can be integrated into an air recirculation system that does not vent to the atmosphere.

Wet scrubbing

Wet scrubbing is a potential control technique for reducing PM emissions from confinement housing ventilation exhaust. A wet scrubber is typically an enclosed tower (with or without packing material) or wetted pad where a particulate-laden gas stream flows counter current to the flow of water. Particulates are removed by direct impaction and interception with or diffusion into water droplets.

Gas Absorption

In a gas absorber, building air is collected and passed through an enclosed (typically packed) tower with the absorption media (e.g., caustic solution) flowing counter-current to the incoming air stream. Gases in the air stream, primarily NH_3 and H_2S, diffuse into and are absorbed by the media. Although water is used as the scrubbing media in many applications, the absorption of the gases can be enhanced using chemical reactions between the target gases and the absorbing media, such as using caustic solution to remove acid gases.

Ozonation

Ozone (O_3) is a strong oxidant that reacts with most organic materials, including organic compounds and microorganisms. Because the half-life of O_3 is very short (10 to 30 minutes), it cannot be stored and must therefore be generated on-site. Typically, O_3 is created inside the confinement building by passing air through an electric field generated by a corona discharge cell.

Ionization

In ionization, gas molecules (e.g., oxygen) acquire a charge from high-energy electrons created by an electrically-generated corona field. The ionized gases adhere to particulates which then move to the nearest grounded surface (e.g., building surface, grounded collection plate). This is the collection mechanism used by electrostatic precipitators (ESPs) in other industries, such as utilities. For AFO applications, commercially-available room ionizers have been used to charge the indoor air molecules. Building surfaces (rather than separate collection plates) have been used to collect PM.

Chemical Oxidation

Oxidation of liquid manures by aerating storage basins or lagoons can reduce emissions of NH_3, H_2S, and VOC. In aerobic stabilization, organic matter (containing carbon, hydrogen, oxygen, nitrogen, and sulfur) is microbially oxidized to carbon dioxide, water, and nitrate and sulfate ions. However, high-rate aeration, as utilized in the treatment of municipal and industrial wastewaters is energy intensive with high utility costs. Consequently, aeration of liquid manures is not typically practiced. Control of gaseous emissions is achieved however using chemical oxidants and biological treatment. Chemical oxidants can be applied in liquid form to stored manure to oxidize NH_3, H_2S, and VOC. Agents such as potassium permanganate and hydrogen peroxide can be applied to the manure surface to reduce emissions. However, a large amount of these types of additives is typically required due to the high of organic matter content of animal manures. The emission reduction achieved by these additives also appears to be short-term, requiring frequent applications to consistently reduce gaseous emissions. Ozone has been used to reduce gaseous emissions from manure slurries by bubbling or diffusing it through the slurry.

Biofiltration

In biofiltration, building air from the ventilation system exhaust passes through a filter bed containing an established, diverse population of aerobic microorganisms. As the air stream flows through the filter media, the microbes oxidize NH_3, H_2S, and VOC emissions. The filter bed

media is usually organic (soil, compost, wood chips, etc.) with sufficient bulk to allow the air stream to pass through and to prevent anaerobic conditions. Additionally, biofilters typically have a piping system to evenly distribute the air and must have a drainage system (either active or passive) to remove excess condensate and precipitation. Although the microbial population requires some moisture (50 to 60 percent) in the filter media bed to maintain activity, excess moisture can lead to anaerobic conditions and failure of the biofilter. A filtration system upstream of the biofilter may be needed in some cases to remove PM since accumulated dust will clog the filter over time. Also, the bed must be rodent and weed free to avoid channeling of gases through the filter media and a loss of performance.

Because biofilters rely on microbial activity, lower ambient temperatures (which slow microbial activity) and excessive variations in the pollutant concentrations in the contaminated air stream affect the pollutant removal performance of biofilters. Consequently, the performance of biofilters will vary seasonally unless provisions are made to preheat the incoming air stream during cold weather.

Bioscrubbing

The concept behind a bioscrubber is similar to that of biofiltration with the exception that the microorganisms are housed in an enclosed packed tower with water circulated countercurrent to the incoming building air, instead of in a filter media bed. As contaminated air is passed through the scrubber, water-soluble compounds (NH_3, H_2S) are absorbed by the water and oxidized microbially. Some scrubber designs contain a vessel that is used as a biological reactor. Effluent from the scrubber is routed to the vessel where additional retention time is provided for microbial oxidation. Periodically, the filter media (especially organic media) must be replaced due to decomposition and compaction that occurs over time. Temperature and variations in pollutant concentrations affect the rate of microbial oxidation in a bioscrubber. However, bioscrubbers are unaffected by PM in the incoming gas stream.

Covering of Manure Storage and Stabilization Units with Biogas Control

Although unsealed covers can suppress NH_3, H_2S, and VOC emissions from manure storage tanks, ponds, and anaerobic lagoons, these pollutant can be emitted when the cover is removed or during land application of the stabilized manure. However, covers that are tightly sealed will not only suppress emissions of NH_3, H_2S, and VOC emissions, but also suppress emissions of methane which can be a primary consistent of biogas produced from anaerobic lagoons. Operators can capture the methane-rich biogas for use as an energy source for the AFO or route the biogas to a control device (e.g., thermal oxidizer or flare). Because of the relatively low rate of methane production from manure storage tanks and ponds due to the smaller population of methanogenic bacteria, use of sealed covers with biogas collection is typically only economically feasible for anaerobic lagoons, which are designed to reduce volatile solids to methane for waste stabilization.

Anaerobic Digestion with Biogas Control

An anaerobic digester is a closed reactor that is heated and possibly mixed to optimize the production of methane from the anaerobic decomposition process. The main components of an anaerobic digester system are the digester, effluent storage, and biogas collection and

utilization equipment. Anaerobic digesters for animal manures may be either completely mixed or plug flow reactors with continuous or semi-continuous flow. The biogas produced contains about 60 to 70 percent methane, about 30 to 40 percent carbon dioxide, and trace amounts of H_2S, and VOC. Operators can use the biogas produced from the digest as a boiler fuel for space or water heating or used to fuel engine-generator sets to produce electricity, with a fraction of the biogas energy used for digester heating. Although Anaerobic digesters equipped with biogas collection and utilization systems reduced emissions of methane, VOC, NH_3, and H_2S; however, NH_3 and H_2S emissions may only be delayed depending on how operator handles the digester effluent.

Biocovers for Liquid Manure Storage and Stabilization Processes

In general, a biocover is a permeable cover made from natural (e.g., chopped straw) or synthetic materials that floats on the surface on a storage of stabilization basin. The biocover provides a boundary layer between the surface of the manure and the atmosphere and a substrate for the growth of aerobic bacteria which microbially oxidize NH_3, H_2S, and VOC as the compounds diffuse through the biocover.

Thermo-chemical Treatment

Solid manures can be disposed of using thermos-chemical technologies which include incineration, gasification, and pyrolysis. Incineration of manures, which occurs under oxygen-rich conditions, releases heat energy and reduces the manure to ash. However, the incinerator exhaust can be a source of PM and gaseous pollutants (e.g., nitrogen oxides) which may require additional emission controls. Gasification occurs under low-oxygen conditions and produces char and synthetic gas, which is similar to biogas, that can be used as an on-site fuel source. Pyrolysis, which is similar to gasification, occurs under oxygen-free (i.e., anaerobic) conditions and produces bio-oil, synthetic gas, and char.

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